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Lu 610 EV

PATENT SPECIFICATION

(11) 1323 751

1323751

DRAWINGS ATTACHED

(21) Application No. 36328/70 (22) Filed 27 July 1970

(44) Complete Specification published 18 July 1973

(51) International Classification B23K 9/12

(52) Index at acceptance H2H 2B4

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(54) METHOD OF CONTROLLING ARC WELDING

(71) We, MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD., a corporation organized under the laws of Japan, of 1006 Oaza Kadoma, Kadoma-shi, Osaka, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a method for controlling the welding voltage by varying the speed of feeding the consumable wire electrode in automatic arc welding and, more particularly, to a method for controlling the welding voltage in such a manner as to provide for an optimum arc length.

In automatic arc welding using a consumable wire electrode (hereinafter referred to as a wire), the welding voltage is usually controlled to a requisite value by varying the speed of feeding the wire as the welding voltage is increased or decreased.

As the welding voltage becomes excessively high, the speed of feeding the wire is increased above a value corresponding to a predetermined rate of fusion of the wire (fusion speed) to decrease the arc length, thereby decreasing the welding voltage to the previous requisite value.

The fusion speed is preset in accordance with a given constant welding current with other conditions being constant, so that a wire feeding speed, which is balanced with respect to the fusion speed, can be evaluated to provide the requisite welding voltage.

The static control characteristic of an arc welding system is the wire-feeding speed to the welding voltage characteristic evaluated on the basis of the desired welding current. If the welding current was held constant, the wire-feeding speed, controlled in correspondence to variation in the welding voltage, would vary in accordance with the static control characteristic that is, along a predetermined characteristic line evaluated for that desired welding current.

Thus, in the welding control system of the type just described where the speed of feeding the wire is changed to provide for a requisite welding voltage, there are static control characteristics relating the wire-feed speed to the welding voltage.

In hitherto proposed systems, the wire-feed speed was varied to control the welding voltage, the control parameters being the welding voltage and the welding current. In the present invention the wire-feed speed is varied with reference to a third parameter that is, the length of the wire electrode from its connection to the power supply terminal to its end at which the arc is struck, usually referred to in the art as the "stick-out" length of the electrode.

According to the present invention there is provided a method for controlling arc welding voltage, comprising the steps of: varying the feeding speed of a consumable wire electrode in accordance with a static control characteristic between said welding voltage and said wire feeding speed; selecting said static control characteristic for a specified welding current and further selecting said static control to obtain a specified ratio of said welding voltage to said wire-feeding speed wherein said ratio of the welding voltage to wire feeding speed in said static control characteristic includes the length of a portion of said wire electrode extruded from a terminal end of a power supply.

In the drawings:

Figs. 1 and 2 are graphs showing examples of static control characteristics of conventional welding control systems of the type described above;

Fig. 3 is a graph of the wire-feeding speed against the welding voltage in a method for automatically controlling the arc welding voltage according to the present invention;

Fig. 4 is a graph co-relating the welding current, welding voltage and wire feeding speed required to ensure effective welding;

Fig. 5 is a schematic side view of a welding apparatus to illustrate the length of the wire electrode extruded from the tip of the welding machine; and

Fig. 6 is a graph showing the relationship

between the motor voltage or wire-feeding speed and the welding voltage when practising the method for controlling arc welding according to the invention.

Figs. 1 and 2 show static control characteristics of convention welding control systems of the aforementioned type.

Referring now to Fig. 1, if it is intended to weld with welding current I_1 and the welding voltage V_1, the welding control system is preset to provide a control characteristic, as shown by plot 8. Plot 8 represents a welding current of I_1, that is, any point on this line gives a wire-feed speed/welding voltage ratio such that the welding current is theoretically I_1. With reference to plot 8, a wire-feed speed f_1, balanced with the fusion speed corresponding to the desired welding current I_1, is obtained for welding voltage V_1. When the welding voltage V_1 is increased by an amount ΔV due to some reason (for instance, due to a slight swing of the operator's hand carrying the welding machine), the operating point P_1, on the characteristic line 8 corresponding to V_1 is shifted along the line 8 to increase the wire-feeding speed by an amount of f.

Assuming that the change of the welding voltage from V_1 has no effect on the value I_1 of the welding current (this substantially corresponds to the case of using a welding source having a sagging V—I output characteristic), the wire fusion speed remains unchanged since the current I_1 remains constant with change of only the wire feed speed by Δf. Thus, the arc length is decreased by an amount represented as:

$$\int_0^t \Delta f dt.$$

Denoting the change in the arc length corresponding to the change ΔV of the welding voltage by Δl,

$$\Delta l = \int_0^t \Delta f dt.$$

The balanced state is recovered when the welding voltage is reduced to V_1.

When adjusting the welding voltage without changing the welding current I_1, the control characteristic itself is replaced in order to maintain the feed speed f_1 constant so that the feed speed equals fusion speed. By replacing the characteristic of line 8 with the one represented by line 10 without changing the welding current I_1, the wire feeding speed f_1 balanced with the wire fusion speed determined by I_1 remains unchanged, so that a new operating point P_1' on the line 10 corresponding to f_1 is established to change the welding voltage from V_1 to V_1'.

Similarly, by replacing the characteristic line 8 with a line 6 the welding voltage is changed from V_1 to V_1''.

Usually, the control characteristic is adjustable either continuously or stepwise within a range as represented by angle θ in Figs. 1 and 2.

According to the invention, the welding voltage is controlled in accordance with the static control characteristics as shown in Fig. 3. In the figure, there are shown a plurality of parallel characteristic lines A_{10}, B_{10}, C_{10}, D_{10} and E_{10} uniformly spaced from one another. It is possible to evaluate a desired control characteristic, represented by line A_i, within a range represented by angle θ between the characteristic line A_{10} and the axis of abscissa representing the welding voltage. Similarly, the desired control characteristics may be evaluated, as represented by lines B_i, C_i, D_i and E_i, within the range of the same angle θ between the respective characteristic lines B_{10}, C_{10}, D_{10} and E_{10} having a maximum slope and the axis of abscissa. It is preferable to have as great a number of the maximum-slope characteristics A_{10}, B_{10}, ..., N_{10} and as small a distance between these characteristics as possible. In an extreme case, it is possible to go continuously from the characteristic A_{10} to the characteristic N_{10}. Of course, a finite number of the characteristics A_{10}, B_{10}, ..., N_{10} may be switched over stepwise. They are different from each other only in their intersections with the axis of the abscissa.

The method of controlling the welding voltage in accordance with the static control characteristics of Fig. 3 according to the invention fundamentally differs from the conventional control method in that according to the invention there are evaluated a plurality of characteristic lines A_i, B_i, ..., N_i corresponding in number to the number of the maximum-slope characteristic lines A_{10}, B_{10}, ..., N_{10} and commonly passing through an operating point P to provide for wire feed speed f_1 when the welding voltage is set to V_1, whereas according to the conventional method there has been evaluated only a single characteristic line containing the operating point P for wire feed speed f_1 with welding voltage set to V_1. Thus, in the method of the present invention, a control system controlling the wire-feed speed in response to changes in the welding voltage, can operate at any point on any of the characteristic lines A_{10}—E_{10}, whereas, in hitherto proposed systems, operation on only one characteristic line was available.

Conventionally, the importance of the slope of the characteristic passing through the operating point P has been disregarded, and it has been only aimed to provide for the required operating point. By the control method according to the invention, the slope of the characteristic passing through the operating point P may be selected by selec-

tively establishing a qualified one of the control characteristics A_i, B_i, C_i etc. containing the operating point P so as to obtain a characteristic having a desired slope.

In one of the welding methods, such parameters as welding current I, welding voltage V and length L of the extruded wire (the distance between the wire tip, at which the arc originates, and the point of the wire in contact with the terminal to the power supply) have important effects on the welding results in such various mechanical characteristics as X-ray performance, bead form, appearance and weld penetration.

Of the above parameters, I, V, and L, only the welding current and voltage I and V have heretofore been controlled. However, it is found that in order to obtain stable welding results it is desirable to have an optimum length of the extruded wire. The welding voltage is heretofore defined to consist of a voltage V_L across the length L of the extruded wire portion and a voltage V_a across the length l_a of the arc, as shown in Fig. 5. Thus, denoting the welding voltage by V,

$$V=V_L+V_a.$$

From this equation it will be apparent that the length L of the extruded wire portion has an important effect on the welding voltage V.

Also, the resistance R of the wire portion of the length L and the welding current I give rise to Joule heat of I^2R to preheat the wire to fuse it at its tip, at which point the arc originates. The extent of preheating the wire, assuming the same wire specifications and the same welding current, depends upon the length L of the extruded wire portion. The greater the length L, the more the wire is preheated to increase the wire fusion speed, thus increasing the wire feeding speed f keeping pace with the wire fusion speed.

In this manner, the length of the extruded wire portion has a significant effect on the wire feeding speed.

Thus, with a change in the length of the extruded wire portion both the welding voltage and the wire fusion speed change accordingly. However, the extent of change of heat transferred to the molten pool is not proportional to the extent of change of the wire feeding speed. Therefore, the change of the length L of the extruded wire portion significantly affects the temperature of the molten pool, weld penetration, bead form, mechanical properties of the fused metal and other welding results. It has been brought to light that the relationships between the welding current, welding voltage and wire feeding speed for obtaining excellent welding results when the length of the extruded wire portion is changed between L_1 and L_6 are usually as shown in Fig. 4. The Figure shows control characteristics for welding currents I_1, I_2, ... For each of the welding currents, the wire feed speed f is plotted as a function of the welding voltage V. For each plot, a change in the length of the extruded wire portion between L_1 and L_6 corresponds to a particular value of the wire feed speed for obtaining excellent welding results. It is to be noted that the plots I_1, I_2, ... may be approximated by straight lines having different slopes with their extensions intersecting with the abscissa axis at different points. The numerical specifications in the relationships of Fig. 4 are determined by the welding method, diameter of the wire electrode used and so forth. By way of example, the relationships among the above parameters in the no-gas composite wire electrode welding using a wire electrode 3.2 mm. in diameter are shown in Fig. 6.

In usual welding, the welding source i.e., welding current, and the welding control, that is, a desired control characteristic as shown in Figs. 1 and 2 are preset.

In case the welding is carried out by carrying the welding torch in the worker's hand, the distance between the tip of the torch and the parts to be welded fluctuates as the worker's hand shakes with respect to the welding, and accordingly the length of the extruded wire portion fluctuates.

In this case, if the welding current is set to I_1 and the control characteristic to E_i in Fig. 4, so that the wire speed f varies with the welding voltage V in accordance with the characteristic 1 in E_i, excellent welding results may be obtained, irrespective of the fluctuation of the length of the extruded wire portion.

Similarly, if the welding current is set to I_2, the control characteristic should be set to D_i in Fig. 4 to obtain excellent welding results.

Likewise, for the welding current I_3 the control characteristic should be set to C_i, for the welding current I_4 in the control characteristic should be set to B_i and so forth. This requirement may be met only by the method according to the invention, with which the control characteristics shown in Fig. 3 are available.

Unless a plurality of control characteristics having different slopes are available for a given operating point P as shown in Fig. 3, the characteristics B_i, C_i, D_i and E_i shown in Fig. 4 can not be obtained.

As has been described in the foregoing, by the welding control method according to the invention excellent welding results may always be ensured, which is very meritorious in industry.

WHAT WE CLAIM IS:—

1. A method for controlling arc welding voltage, comprising the steps of: varying the feeding speed of a consumable wire electrode in accordance with a static control characteristic between said welding voltage and said

wire feeding speed; selecting said static control characteristic for a specified welding current and further selecting said static control characteristic to obtain a specified ratio of said welding voltage to said wire feeding speed, wherein said ratio of the welding voltage to the wire feeding speed in said static control characteristic includes the length of a portion of said wire electrode extruded from a terminal end of a power supply.

2. A method for controlling arc welding voltage substantially as hereinabove described with reference to Figs. 3 to 6 of the accompanying drawings.

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Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1973.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

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2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG. 1 PRIOR ART

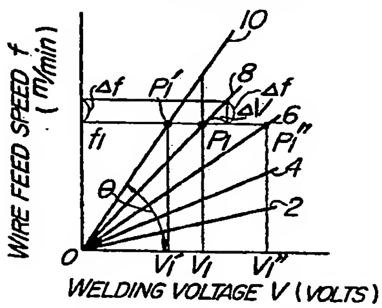


FIG. 2 PRIOR ART

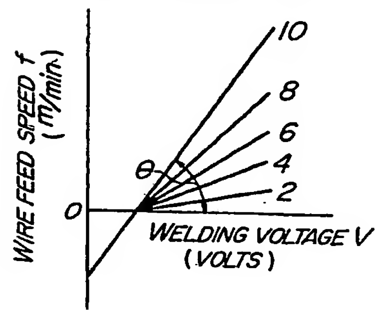


FIG. 3

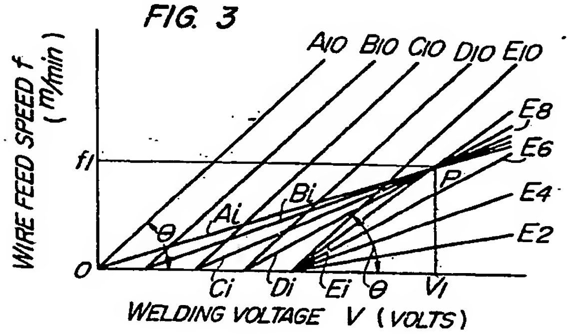


FIG. 4

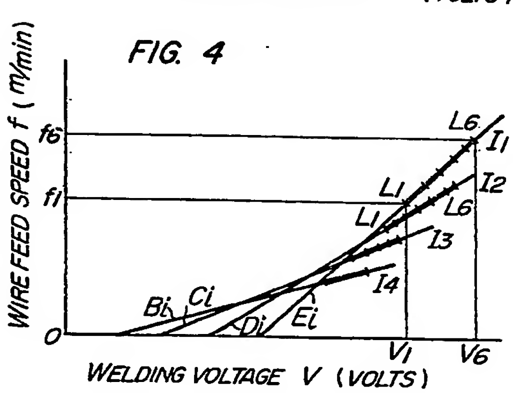
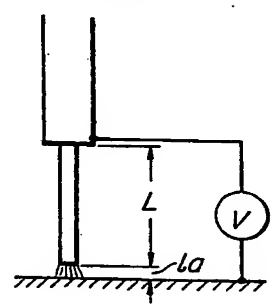


FIG. 5



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Sheet 2

FIG. 6